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# High-Power Options for LANSCE

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# Abstract

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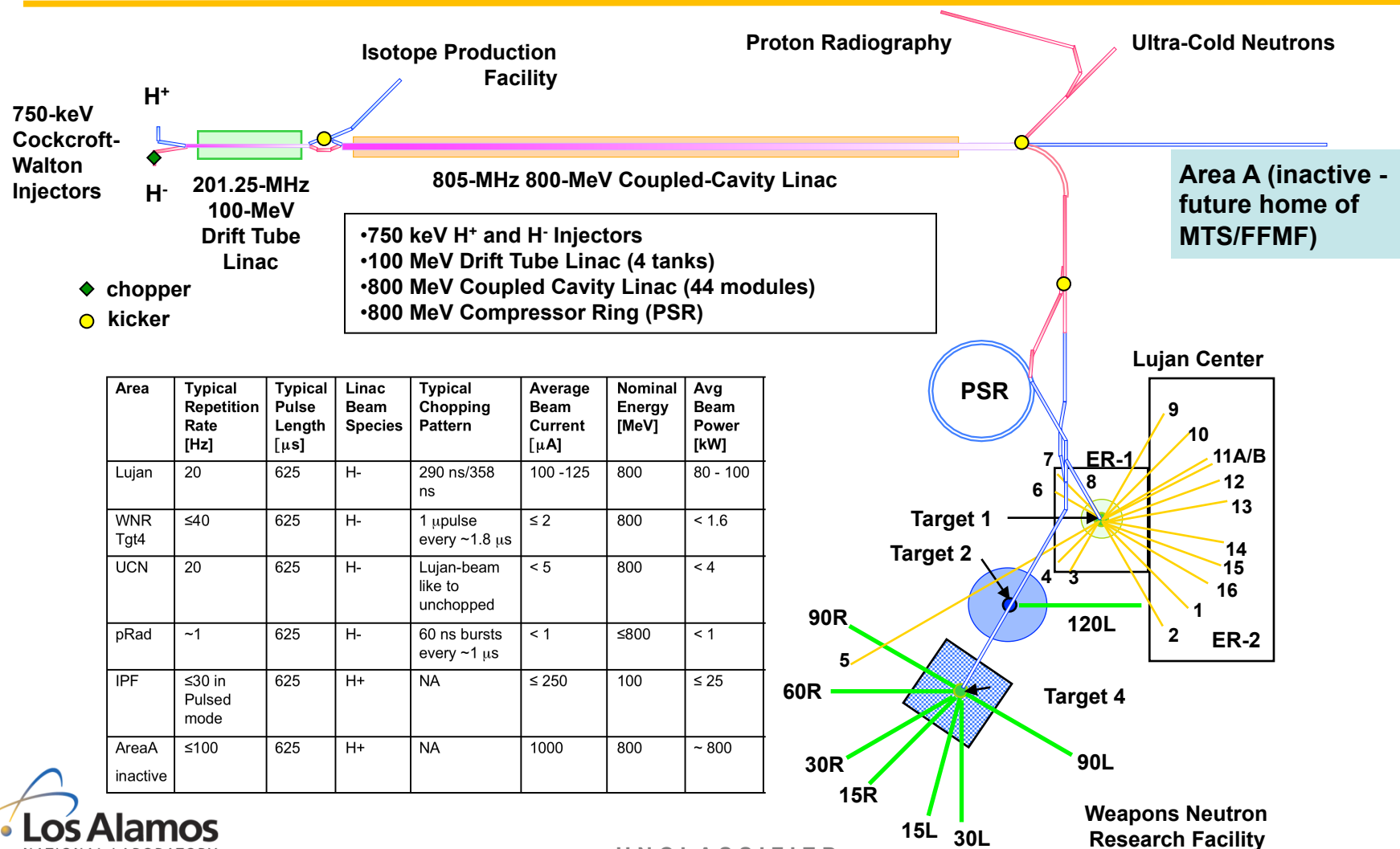
The LANSCE linear accelerator at Los Alamos National Laboratory has a long history of successful beam operations at 800 kW. We have recently studied options for restoration of high-power operations including approaches for increasing the performance to multi-MW levels. In this paper we will discuss the results of this study including the present limitations of the existing accelerating structures at LANSCE, and the high-voltage and RF systems that drive them. Several options will be discussed and a preferred option will be presented that will enable the first in a new generation of scientific facilities for the materials community. The emphasis of this new facility is "Matter-Radiation Interactions in Extremes" (MaRIE) which will be used to discover and design the advanced materials needed to meet 21<sup>st</sup> century national security and energy security challenges.

# Outline

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- LANSCE Facility Overview
- Motivation – MTS & MaRIE/FFMF
- Existing Limitations
- High-Power Options
- Our Preferred Option

# LANSCCE Facility Overview



# Linac Performance - Historical, Demonstrated & Present

- **Historical Performance**

- 120 Hz x 625  $\mu$ s beam gates; 7.5% duty factor (100-Hz  $H^+$ , 20-Hz  $H^-$ )
- Combined and simultaneous  $H^+/H^-$  operation (limited by peak RF power)
- Typical maximum peak beam current ( $H^+$ ): 16.5 mA
- RF duty factor:  $\sim 10\%$
- *800-kW average beam power (800 MeV, 1-mA average  $H^+$  current)*
- High-power operation halted in 1998

- **Demonstrated Performance (non-coincident,  $H^+$  only)**

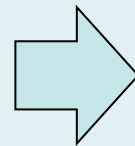
- RF duty factor:  $\sim 12\%$  (1980's?)
- Beam gates: 1225  $\mu$ s (800 MeV, 80 Hz, LPSS Demo 1996)
- Peak  $H^+$  beam current: 21 mA (800 MeV, LPSS Demo 1996)
- *Demonstrated 1-MW Average to Area A (800 MeV, 120-Hz  $H^+$ , 1983)*

- **Present Performance**

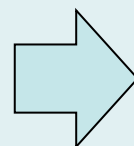
- 60 Hz Operation (limited by 7835 in DTL 201-MHz RF system)

Path to Future High-Power Operations

LANSCÉ  
Risk Mitigation



MTS  
1MW



MaRIE/FFMF  
2 MW

# Linac Risk-Mitigation efforts will enable a return to high-power operations by 2016 – Restores 120-Hz capability.

Linac Risk Mitigation plans will provide needed linac modernization by 2016.



**Install modern, maintainable Instrumentation & Control and Diagnostics systems**

**Refurbish the 805-MHz RF amplifier systems for the Coupled Cavity Linac (100 - 800 MeV)**

**Remediate accelerator structures, supporting equipment and power supplies**

**Replace the 201-MHz RF system for the Drift Tube Linac (0.75 - 100 MeV) to restore 120-Hz operation**

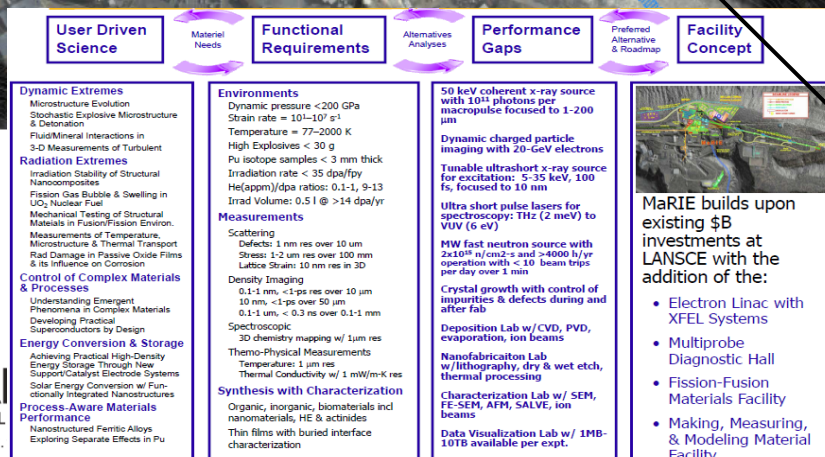
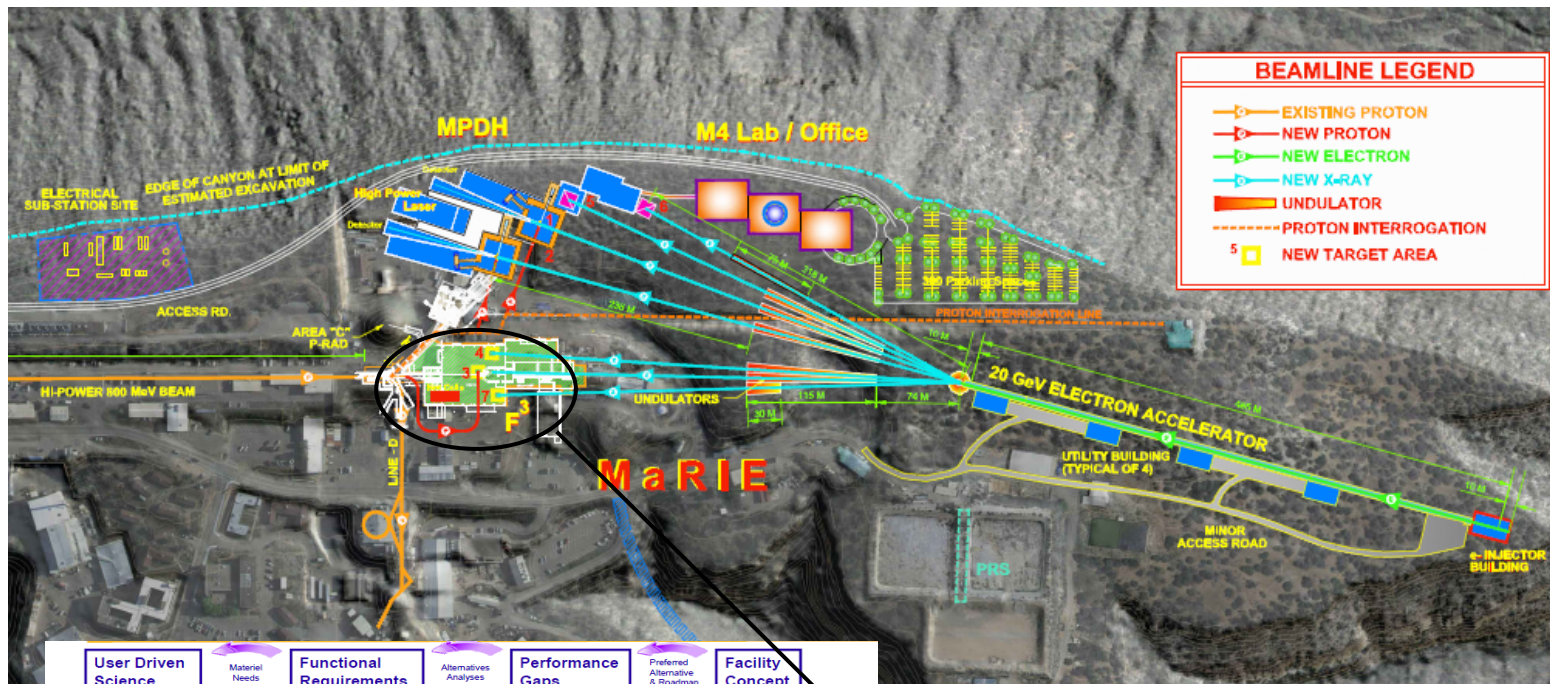
***201.25-MHz RFQ Test Stand / Front-End Replacement***

**Risk Mitigation Projects will ensure reliable operations and enable high-power applications.**

***Multi-Year Effort & Funding: FY09-FY11 \$40.3M, FY12-FY17 \$20M-\$30M/yr***



# Matter-Radiation Interactions in Extremes (MaRIE) is the LANSCE future.



MaRIE includes:

- 20-GeV Electron Linac / XFEL
- Beam Power Upgrade to 2 MW
- Enhanced Experimental Capabilities

## Our motivation to deliver higher-power beams is to produce intense neutrons for MTS and FFMF.

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- 1 MW – Materials Test Station (MTS)
  - Baseline design for the MTS; achieves 4.5% per calendar year fuel burn-up in highly enriched fuel and 18 dpa/yr damage in steels.
  - 800 MeV, 4400 hrs of full beam power/year
- 2 MW – Fission-Fusion Materials Facility (FFMF) / IFMIF Equivalent
  - IFMIF equivalent neutron flux and irradiation volume; 50 dpa/FPY and 0.3 liter with >20 dpa
  - Achieves  $2.5 \times 10^{15}$  n/cm<sup>2</sup>/s peak flux in fuel irradiation region, 6%/yr fuel burn-up, 28 dpa/yr in iron.
  - Rep Rate  $\geq 100$  Hz, Pulse Length  $\geq 0.75$  ms, 800 MeV  $\geq$  Energy  $\leq 3$  GeV
- 5 MW – FFMF / JOYO Equivalent
  - Achieves peak neutron flux of  $5 \times 10^{15}$  n/cm<sup>2</sup>/s
  - Would be highest neutron flux in the world; equivalent to JOYO reactor; exceeds BOR-60 ( $3.4 \times 10^{15}$  n/cm<sup>2</sup>/s)
  - Same operational parameters as 2 MW (rep rate, etc.)



## The Materials Test Station (MTS) will enable testing fission reactor fuels and structural materials in a fast-neutron environment.

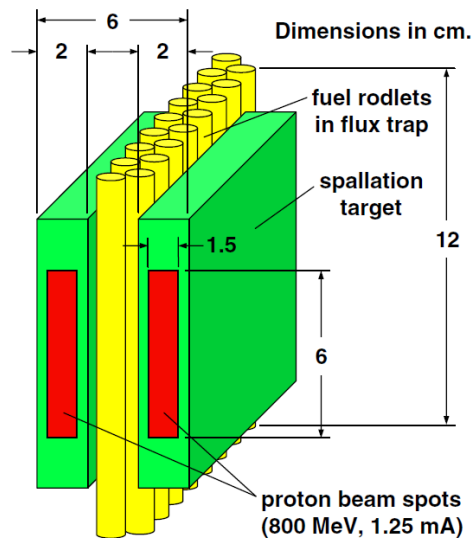


Fig. 1. Basic configuration of the MTS target assembly.

- LBE Target
- 1-MW LANSCE beam will produce  $10^{17}$  neutrons/sec.

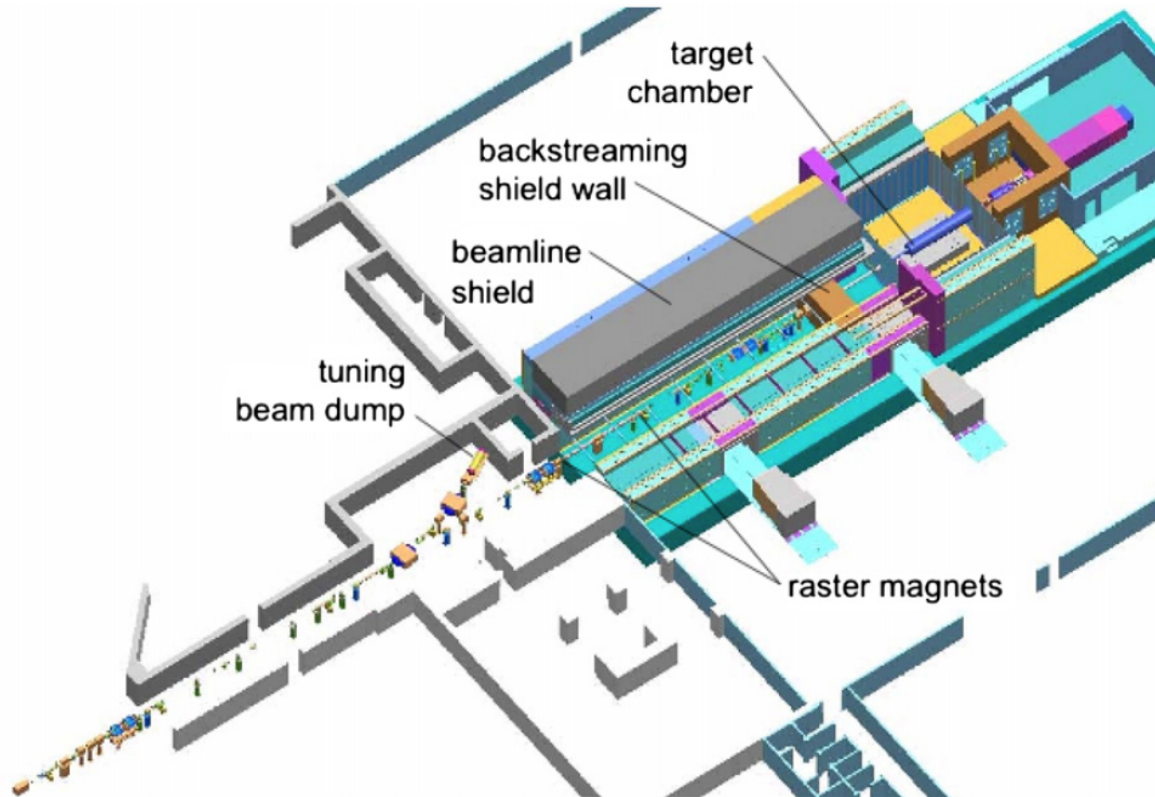
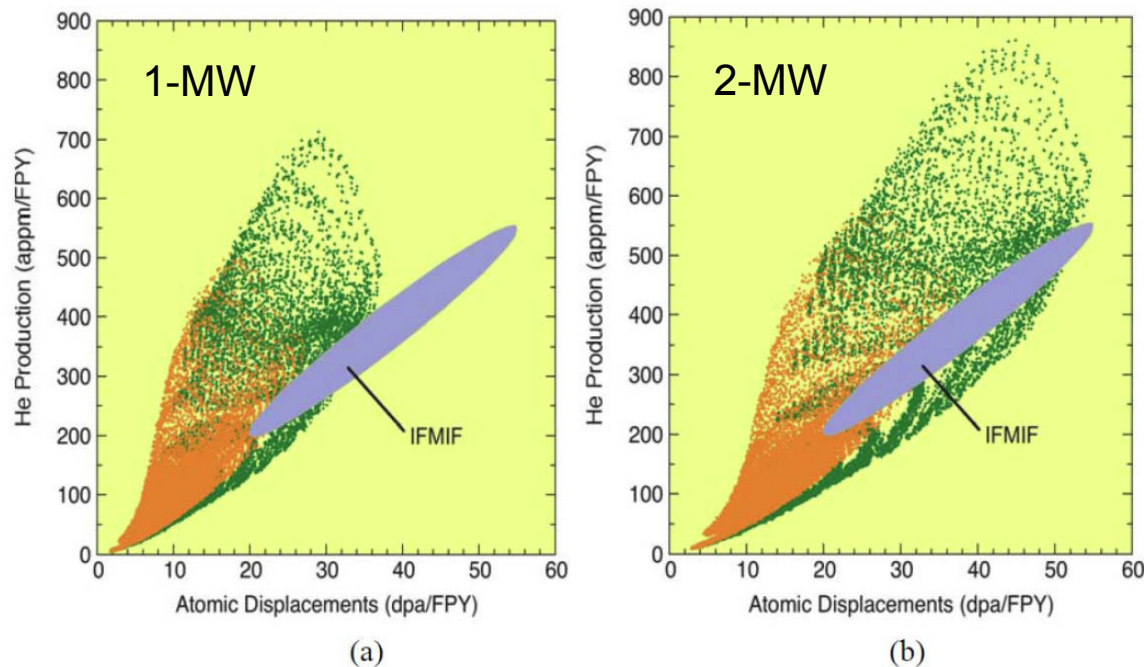


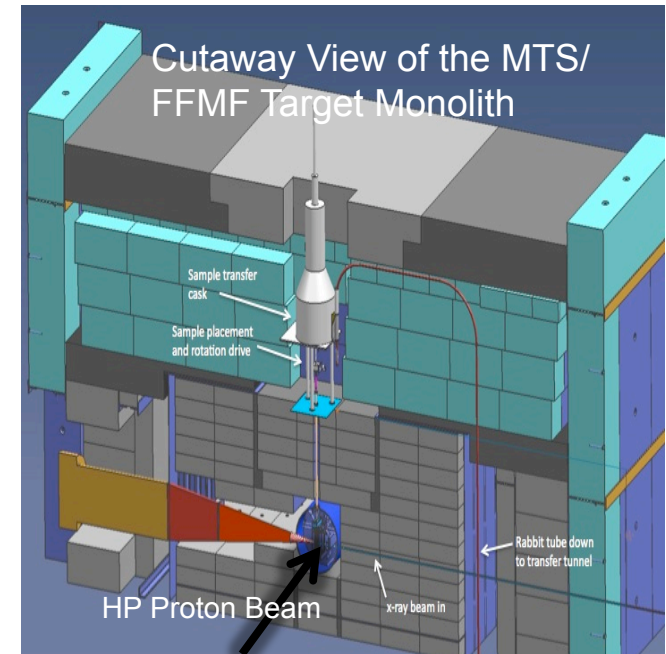
Fig. 4. Physical layout of the beam transport system.

E. J. Pitcher, "The materials test station: A fast-spectrum irradiation facility," *Journal of Nuclear Materials*, 377, Issue 1, 30 June 2008.

# The MTS/FFMF is the next high-power mission for LANSCE.

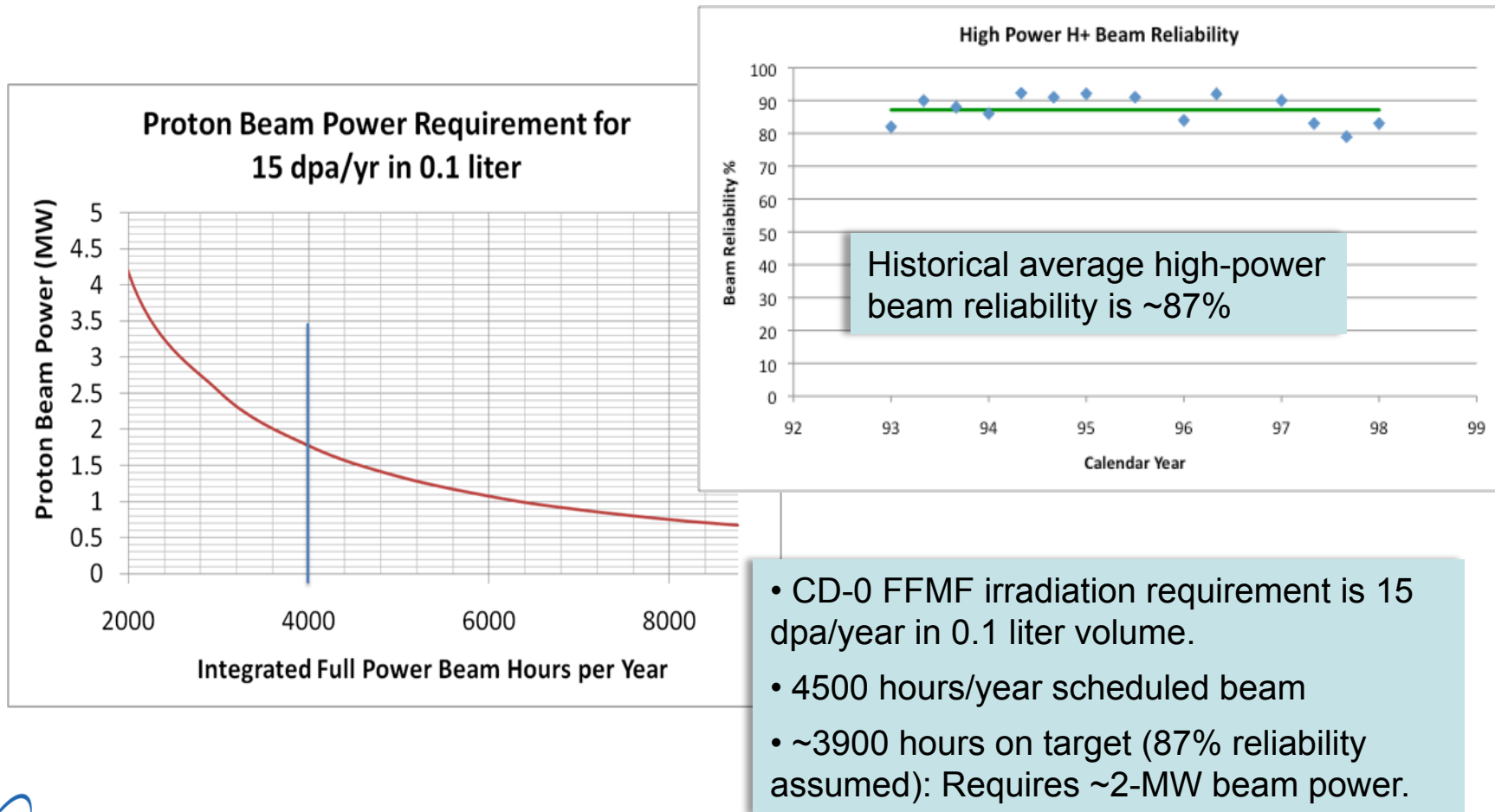


Calculated displacement and helium production rates in the MTS at (a) 1-MW and (b) 2-MW beam powers. Also shown is the parameter space covered by the IFMIF-HFTM (blue ellipse).



FFMF in-situ characterization and multi-probe capabilities integrated into the MTS target assembly.

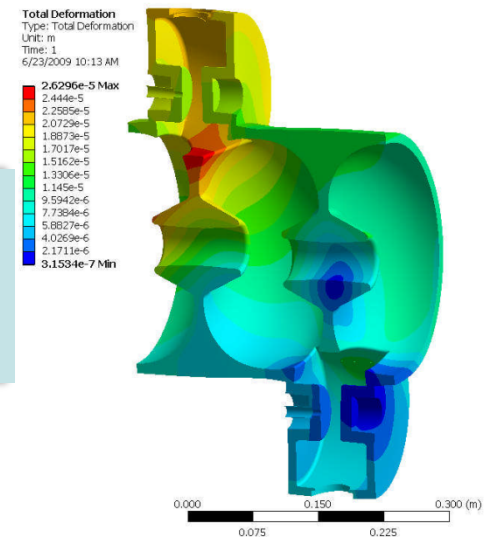
# Neutron environment requirements and accelerator system reliability/availability drive upgrade paths.



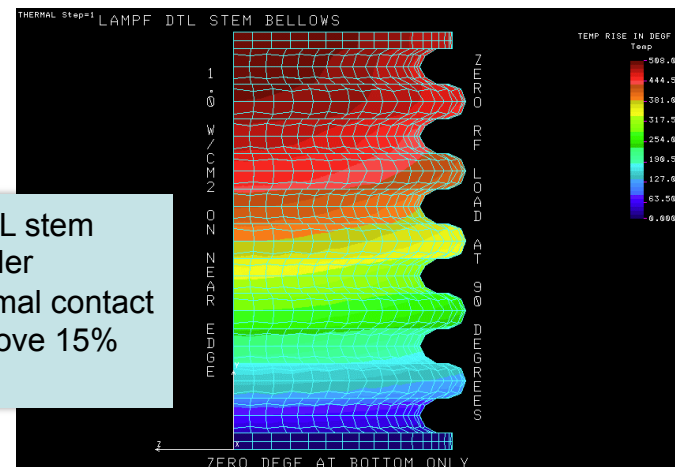
## Some simple assumptions were made to develop the high-power options.

- Free parameters to increase beam power include:
  - RF duty factor
  - peak beam current
  - final beam energy
- To reduce cost impacts use existing structures, if possible.
- Operational systems and existing structures constraint the RF duty factor.

ANSYS Calculations show plastic deformation of CCL cavities at 15% RF duty factor. (2009)



COSMOS model of DTL stem bellows shows that under conditions of poor thermal contact melting could occur above 15% RF duty factor. (2005)



## Operational and accelerator structure limits constrain the upgrade paths to higher average beam power.

Maximum Safe RF Duty-Factor Limits for the LANSCE Linac Structures and RF Systems

	DTL	CCL	201.25 MHz (HVDC PS)	805 MHz (Klystron)
RF	<b>12.4%</b>	<b>12.2%</b>	11.8% (10% beam) – Present	<b>12.0%</b> (120 Hz, 1 ms)
Duty	(structure limited)	(structure limited)	<b>12.5%</b> (10.7% beam) – Post LRM	
Factor				

- DTL
  - Poor thermal contact / poor cooling of bellows on drift-tube stems.
  - Post-coupler heating may also contribute.
  - Significant field errors (measured vs. design at location of tuning slugs)
  - Operating set-point errors (assumed  $\pm 5\%$  assumed)
- CCL
  - Structures cooled via external cooling channels.
  - Need to avoid plastic deformation (15% limit)
  - Bead pull measurement reveals  $\pm 6\%$  field amplitude variations
  - Operating set-point errors (assumed  $\pm 5\%$  assumed)
- Klystron peak-power and power supply name-plate ratings limit RF duty factor.



## High-Power Upgrade Options (All assume 100-Hz rep rate, H+)

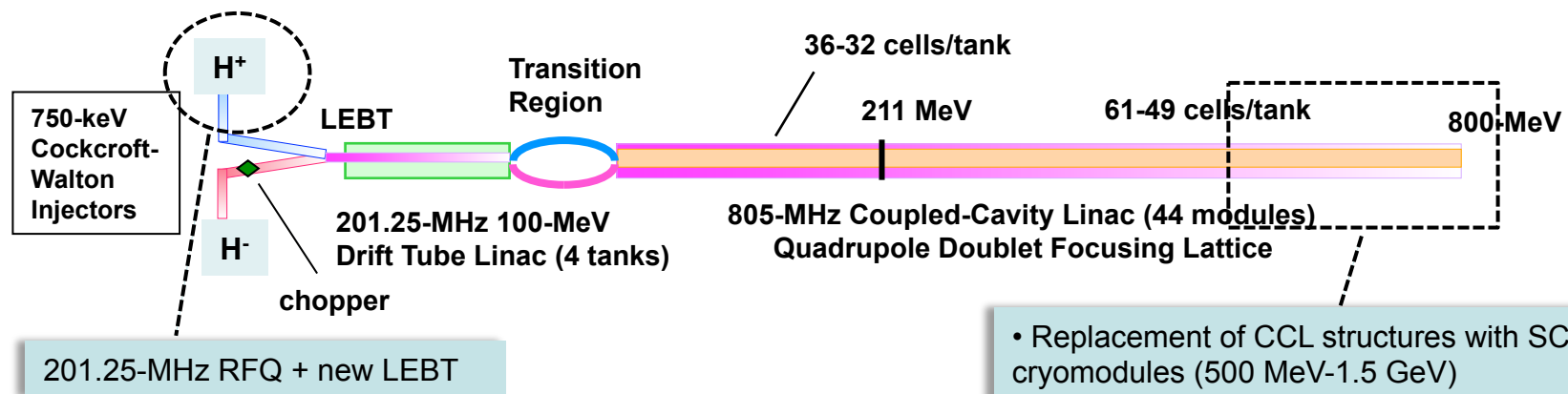
Option	Beam Power (MW)	Requirements	Beam Pulse Length ( $\mu$ s)	RF Duty Factor (%) DTL, CCL, SCL	$E_{\text{final}}$ (GeV)	$I_{\text{peak}}$ (mA)	$I_{\text{avg}}$ (mA)	SC cryomodules/ klystrons
1-MW Option 1	1	Increase duty factor	770	12.3, 10.8, N/A	0.8	16.5	1.25	N/A
1-MW Option 2	1	Increase duty factor & peak beam current	688	11.3, 9.8, N/A	0.8	18.5	1.25	N/A
Max. Beam Power	1.16	Increase duty factor & peak current	797	12.4, 11.0, N/A	0.8	18.5	1.45	N/A
2-MW Option 1	2	Fix DTL field errors, Increase duty factor & peak beam current, add 201.25-MHz RFQ, upgrade HPRF & HVDC	922	13.2, 12.3, N/A	0.8	27.5	2.5	N/A
2-MW Option 2	2	Increase duty factor & peak beam current, add 201.25-MHz RFQ, upgrade HPRF & HVDC, increase final beam energy	788	12.4, 10.9, 9.7	1.5	17.0	1.33	18/72
5-MW Option 1, Not Viable	5	Increase peak beam current, increased RF power to CCL	913					
5-MW Option 2	5	Increase final beam energy, increase peak beam current, add 402.5-MHz RFQ & 402.5-MHz DTL, Upgrade HPRF, HVDC	913	TBD	1.5	37.0	3.3	18/72
5-MW Option 3	5	Increase final beam energy, increase peak beam current, add 402.5-MHz RFQ & 402.5-MHz DTL, Upgrade HPRF, HVDC	913	TBD	2.0	28.0	2.5	25/100

Risk mitigation efforts will restore 1-MW capability.

This is our preferred option that meets the 2-MW MTS/FFMF requirements.

Beyond 2 MW requires significant upgrades.

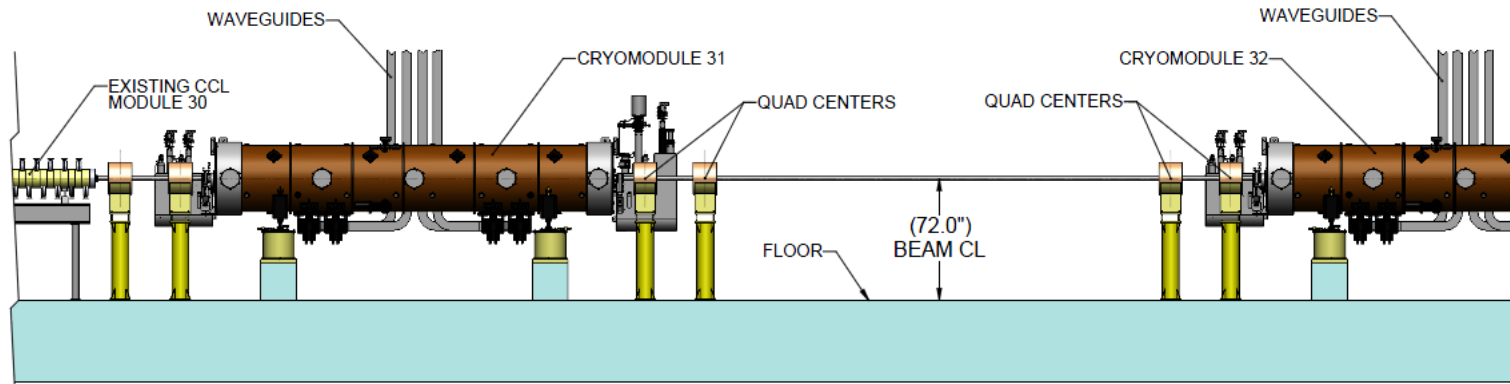
## The Preferred 2-MW Option (baseline)



- 201.25-MHz RFQ type TBD.
- 18 SNS-like, 805-MHz,  $\beta=0.81$  ( $E_0 T=15.8$  MV/m ) SC cryomodules
- Requires replacement of CCL high-power RF systems with 72 (18 x 4; 4 cavities/cryomodule) lower-power klystrons – alternatives to be explored.
- Preliminary beam dynamics simulations completed – detailed end-to-end simulations planned.
- Final Beam Energy = 1.5 GeV

Beam Pulse Length ( $\mu$ s)	RF Duty Factor (%) DTL, CCL, SCL	$E_{\text{final}}$ (GeV)	$I_{\text{peak}}$ (mA)	$I_{\text{avg}}$ (mA)
788	12.4, 10.9, 9.7	1.5	17.0	1.33

## Preferred 2-MW option has many advantages.



- One-for-one replacement of a CCL module with an SNS-like SC cryomodule.
- Uses existing tunnel wave-guide penetrations – minimizes waveguide runs.
- Uses existing klystron galleries.
- Takes advantage of SNS design, non-reoccurring engineering, and R&D.
- Upgradeable to higher beam powers.

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# Questions?